

Twelve-Year Study Monitoring Two Species of Pond-Breeding Salamanders in Northeast Ohio¹

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ABSTRACT. Studies suggest a worldwide decline in amphibians during the last four decades, however these studies have rarely included long-term (>10 years) studies involving interacting species of North American salamanders. In this study, populations of spotted salamanders (*Ambystoma maculatum*) and Jefferson Salamanders (*A. jeffersonianum*) at Cuyahoga Valley National Recreation Area in northeast Ohio were monitored for 12 years from 1990-2001 to provide baseline data and to test the null hypothesis that these populations are not in decline. The study sites include a semipermanent wetland (ca 1500 m²) and a temporary wetland (10 m²) that are 80 m apart on a wooded hill. I monitored populations at each wetland by estimating egg mass density, mean number of eggs per mass, and embryo mortality. From these I calculated estimates of egg and hatchling densities and the total number of eggs, surviving embryos, and adult females breeding at each wetland. The densities of eggs and hatchlings of each species were greater in the large pond and greater for spotted salamanders. The number of eggs/egg mass was greater in the large pond and was greater from 1995-1999 than 1990-1994 and 2000-2001. Embryo mortality supports predictions based on water temperature and pH. Spotted salamander embryo survival was correlated with increasing pond water pH. There was no significant trend over time in the number of embryos surviving to hatch each year for either species. This long-term study supports the hypothesis that these populations are in stable coexistence and demonstrates that some populations of North American salamanders are not in decline.

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INTRODUCTION

Reports that amphibians have declined from pristine habitats on several continents raised concerns there may be a global amphibian decline (Blaustein and Wake 1990). A recent meta-analysis of more than 200 studies on amphibian populations indicates that there has been a worldwide decline during the last four decades for reasons that are still unknown (Houlahan and others 2000). However, few of these studies were on North American salamanders, were conducted for more than 10 consecutive years, or involved two or more interacting species. The few long-term studies on North American salamanders often suggest stable populations (Hairston 1996; Sexton and others 1998), fluctuations due to annual climatic variation (Pechmann and others 1991), or fluctuations due to competition (Cortwright 1998). More baseline data is needed to address the question of whether salamanders are in decline in the USA or if their populations fluctuate with climate and competitive interactions. These studies need to be at least 7-10 consecutive years to detect biologically meaningful trends in long-lived species such as pond-breeding salamanders of the genus *Ambystoma* (Sexton and others 1998; Pechmann personal communication).

Throughout their range from southern Indiana and northern Kentucky, to southern New England and northern New Jersey, the Jefferson salamander (*Ambystoma jeffersonianum*) often coexists with spotted salamanders (*A. maculatum*) (Thompson and Gates 1982; Cortwright 1988; Brodman 1995). These species spend

most of their lives underground in wooded habitats, but return to semipermanent and temporary ponds in late winter-early spring to breed (Petranka 1998). Females typically lay eggs in large masses and attach them to vegetation in the water (Brodman 1995; Petranka 1998). Growth and survivorship of the aquatic larvae are under the influence of density-dependent regulation due to competition and intraguild predation until they metamorphose during the summer (Wilbur 1972; Cortwright 1988; Brodman 1996). Studies conducted under controlled conditions in field pens and laboratory aquariums indicate that spotted salamander and Jefferson salamander larvae are in a competitive balance and should maintain a stable coexistence (Brodman 1996, 1999). The purpose of this study is to provide baseline data on coexisting Jefferson and spotted salamander populations and to provide insight on whether these populations of salamanders are in decline, fluctuate with climate, or maintain a stable coexistence. To test the null hypothesis that these populations have not changed from 1990-2001, presented here are data on 12 consecutive years of monitoring populations at two breeding sites.

METHODS

Spotted salamander and Jefferson salamander populations were monitored annually from 1990 to 2001 at two breeding ponds at Cuyahoga Valley National Recreation Area in northeast Ohio (Fig. 1). The ponds are located on a wooded hill separated by 80 m. The large pond is approximately 1500 m² and 1.0 m deep at its maximum size in early spring, and at least 800 m² and 0.25 m deep throughout the year in most years, with the exception of 1991 and 1996 when it dried during

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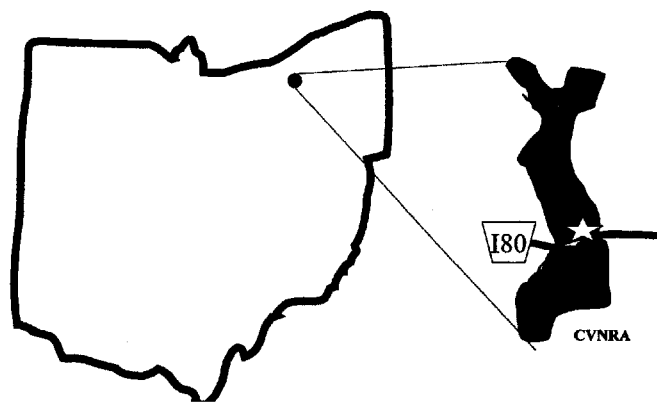


FIGURE 1. Map of study site (star) within the Cuyahoga Valley National Recreation Area (CVNRA) in northeast Ohio.

the summer. The large pond is dominated by emergent woody shrubs, primarily buttonbush (*Cephalanthus occidentalis*) and willows (*Salix* sp.). Cover by emergent vegetation and turbidity of pond water has increased during the 12-year study. The small pond is only 10 m² and 0.6 m at its maximum depth. It holds water throughout the wettest years but dries most summers. The small pond has no emergent vegetation. Both sites have abundant submerged logs and leaf litter.

The sites were visited twice a year in March and April to estimate egg mass densities and embryo mortality. The visits were timed with the life history characteristics of each species. The first visit was within 3 weeks after conditions that are typical for the breeding of each species but before eggs began to hatch. Jefferson salamanders typically breed in early to mid March when water temperatures reach about 10° C, while spotted salamanders often breed a week later within 18 h of rain when water temperatures reach about 11° C (Brodman 1995). Jefferson salamander eggs hatch in 28 days while spotted salamander eggs hatch in 50 days (Brodman 1995). In most years, during my first visit Jefferson salamander eggs were close to hatching and the spotted salamanders had finished breeding. Egg mass densities and embryo mortality of Jefferson salamanders were usually determined during the first visit. The second visit was used to estimate spotted salamander embryo mortality and in some years to determine egg mass density if my first visit came before the final wave of spotted salamander breeding.

Egg mass densities at the large pond were estimated by establishing eight random transects across the pond. A circular 0.5 m² hoop was placed every 2.0 m on each transect delineating a total of 188 samples. All egg masses within the hoop were counted and identified to species in each sample. Spotted salamander egg masses are globular and surrounded with a dense and stiff jelly, while those of Jefferson salamanders are sausage-shaped and less firm (Downs 1989; Minton 2001). I confirmed these distinguishing egg mass characters by identifying larvae and juveniles raised from eggs collected at this site (Brodman 1995, 1996, 1999). Egg mass densities at the small pond were determined

by counting all of the egg masses. Mean egg mass densities were calculated from the samples to represent an estimate of overall density in the large pond. For each species the number of eggs/egg mass and embryo mortality were determined by counting the number of living and dead embryos in a random sample of 24 egg masses from the large pond and a random sample of 10 egg masses from the small pond. I wanted to minimize the number of egg masses that I disturbed and found that these sample sizes were adequate to estimate the mean number of eggs per egg mass while keeping the standard error to just 4-13% of the mean. Eggs were counted when embryos were near hatching in Harrison stages 37-43 (Harrison 1969). Recently hatched eggs were also counted if the egg envelope remained in the egg mass. These values were extrapolated to calculate rough estimates of the total number of larvae that hatch by multiplying mean egg mass density times mean number of surviving embryos. The rough estimated density of hatchlings was calculated by multiplying the estimate of mean surviving embryo density times the area of the pond.

Water temperature and pH was measured during each visit. These variables were measured three times a week from March through June from 1990-1992 and the pH varied from 5.8-6.1 (Brodman 1995). Monthly climatic data was obtained from Accu-weather™. Data collected from 1990-1993 from the large pond has been published (Brodman 1995) but will be used here for comparison. Kendall's nonparametric correlation (Tau) and ANOVA were used as exploratory analyses to test the hypothesis that there are no significant population trends among years, water temperature, or pH. Kendall's correlation is more powerful than Pearson's correlation for detecting moderate (16-18%) declines in *Ambystoma* populations (Pechmann 2001). ANOVA was used to test the hypothesis that there are no significant differences among ponds and species.

RESULTS

There was no significant trend of mean egg mass density at either pond and for either species from 1990-2001 (Fig. 2) except for a slight decrease in spotted salamander egg masses at the small pond ($T = -0.485$, $n = 12$, $p = 0.028$). Jefferson salamanders varied from 1.4-2.1 with a mean of 1.7 ± 0.1 (SE) egg masses per m² in the large pond and 0.2-2.3 with a mean of 1.2 ± 0.2 egg masses per m² in the small pond, while spotted salamanders varied from 3.0-7.4 with a mean of 5.7 ± 0.35 egg masses per m² in the large pond and 1.1-5.9 with a mean of 3.1 ± 0.42 egg masses per m² in the small pond. The number of spotted ($F = 21.87$, $df = 1$, 10 , $p = 0.009$) and Jefferson salamander ($F = 12.37$, $df = 1$, 10 , $p = 0.025$) eggs per egg mass changed significantly from 1990-2001 at the large pond (Fig. 3). The number of spotted salamander eggs per mass from 1995-1999 was 98.2 compared to 77.5 eggs per mass from 1990-1994 and 2000-2001, while Jefferson salamanders had 31.9 eggs per mass from 1990-1995 compared to 34.9 from 1996-2001. There were no significant trends in the size of egg masses at the small pond.

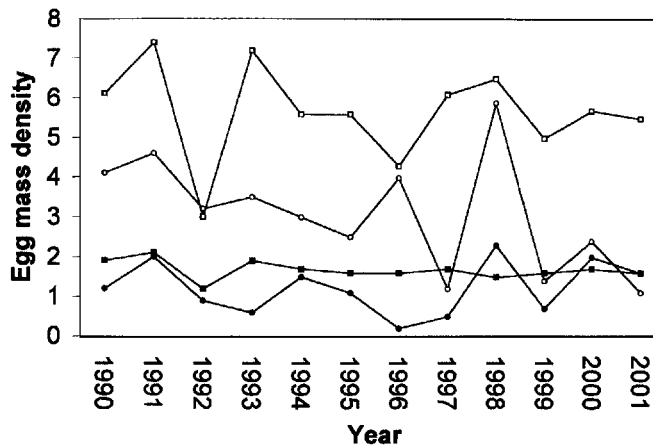


FIGURE 2. Egg mass density of spotted (open) and Jefferson (closed) salamanders in the large (squares) and small (circles) ponds from 1990-2001.

Egg density for each species at each pond was calculated by multiplying mean egg mass density times the mean number of eggs per egg masses. There were no significant trends in mean egg density from 1990-2001 (Fig. 4). Spotted salamander mean egg mass density ($F = 3.77$, $df = 1, 46$, $p = 0.05$), the number of eggs per mass ($F = 260.5$, $df = 1, 46$, $p < 0.001$), and egg density ($F = 67.5$, $df = 1, 46$, $p < 0.001$) were significantly greater than the Jefferson salamanders. The mean egg mass density ($F = 7.78$, $df = 1, 46$, $p = 0.008$) and egg density ($F = 7.70$, $df = 1, 46$, $p = 0.008$) were significantly greater in the large pond than the small pond.

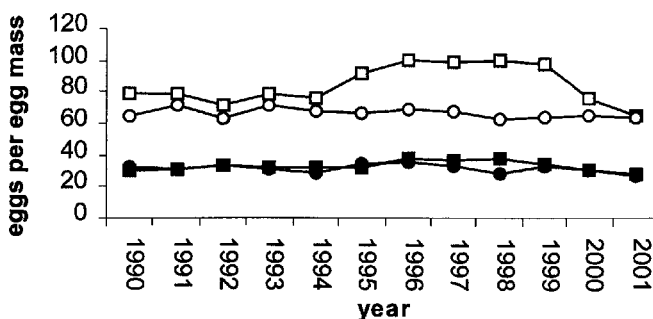


FIGURE 3. Mean number of eggs per egg mass of spotted (open) and Jefferson (closed) salamanders in the large (squares) and small (circles) ponds from 1990-2001.

The percentage of embryos that survived to Harrison stages 37-43 significantly increased from 1991-2001 in spotted salamanders at both the large ($T = 0.636$, $n = 11$, $p = 0.006$) and small ($T = 0.440$, $n = 11$, $p = 0.05$) ponds (Fig. 5). Survival increased from a mean of 64.1% during 1991-1996 to 76.3% during 1997-2001 at the large pond, and from 68.5% during 1991-1995 to 70.6% during 1996-2001 at the small pond. The mean Jefferson salamander embryo survival was 87.7% at the large pond and 82.6% at the small pond. The density of

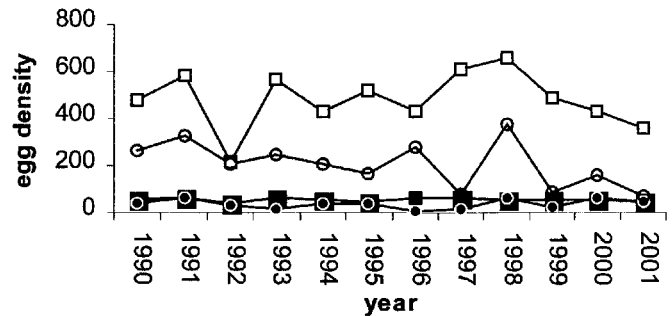


FIGURE 4. Mean egg density of spotted (open) and Jefferson (closed) salamanders in the large (squares) and small (circles) ponds from 1990-2001.

surviving embryos (Fig. 6) was calculated by multiplying egg density times the percent survival, and the number of surviving embryos (Fig. 7) was calculated by multiplying the density of surviving embryos by the area of the pond. The number of surviving spotted salamander embryos at the small pond significantly decreased from 1991-2001 ($T = -0.455$, $n = 11$, $p = 0.05$). There was no significant trend in the density or number of surviving embryos from 1991-2001 for either species at the large pond.

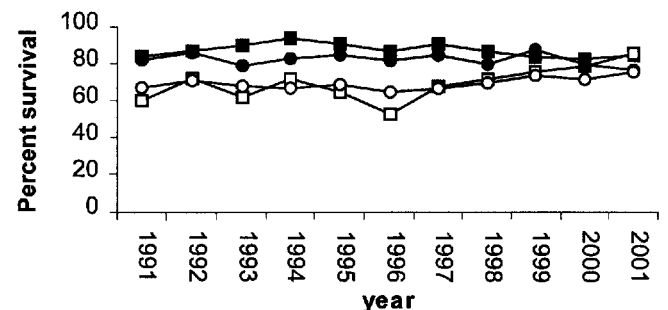


FIGURE 5. Mean percent survival of embryos to Harrison stages 37-43 of spotted (open) and Jefferson (closed) salamanders in the large (squares) and small (circles) ponds from 1991-2001.

The percentage of spotted salamander embryos that survived was significantly lower than Jefferson salamander ($F = 83.1$, $df = 1, 46$, $p < 0.001$); however, the number

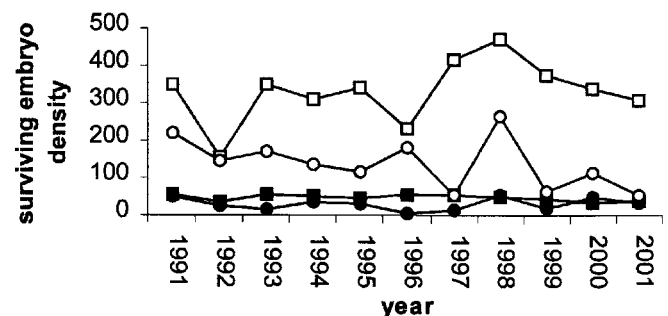


FIGURE 6. Estimated embryo density of spotted (open) and Jefferson (closed) salamanders in the large (squares) and small (circles) ponds from 1991-2001.

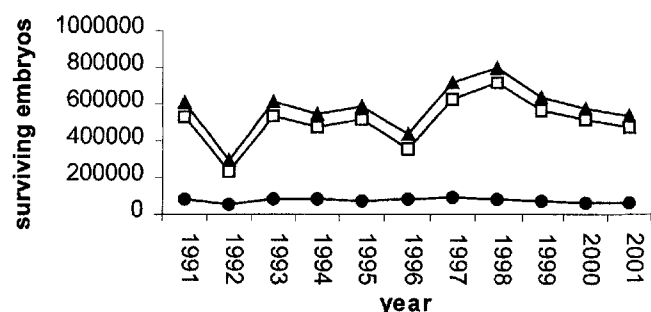


FIGURE 7. Estimated number of surviving embryos of spotted (squares), Jefferson (circles), and total salamanders (triangles) at both ponds from 1991-2001.

of spotted salamander embryos that survived was significantly greater ($F = 13.6$, $df = 1, 46$, $p = 0.001$). The density of surviving embryos was significantly greater in the large pond than the small pond ($F = 8.17$, $df = 1, 42$, $p = 0.007$).

The number of eggs deposited in these ponds ranged annually from 325,000-983,000 spotted salamander eggs with an annual mean of 723,992 eggs, and from 59,000-100,000 Jefferson salamander eggs with an annual mean of 85,124. The overall number of surviving spotted embryos ranged from 233,000-711,000 with a mean of 499,239, and Jefferson salamanders ranged from 52,000-86,000 with a mean of 72,435. The ratio of spotted to Jefferson salamanders ranged from 4.5 to 9.5 with a mean \pm SE of 6.9 ± 0.5 . There was no significant trend in the number of surviving embryos of spotted ($T = 0.127$, $n = 11$, $p = 0.586$) and Jefferson salamanders ($T = -0.345$, $n = 11$, $p = 0.139$) from 1991-2001.

Annual measurements of pond water pH ranged from 5.8-6.5 (Fig. 8) and increased significantly from 1990-2001 ($T = 0.785$, $n = 12$, $p = 0.001$). There was a positive correlation between pH and the percentage of spotted salamander embryo survival at both the large pond ($T = 0.674$, $n = 12$, $p = 0.005$) and small pond ($T = 0.583$, $n = 12$, $p = 0.017$). There were no significant trends between temperature or precipitation and any of the population measures for either species.

DISCUSSION

Spotted salamander egg density was greater in the large study pond than other reported populations

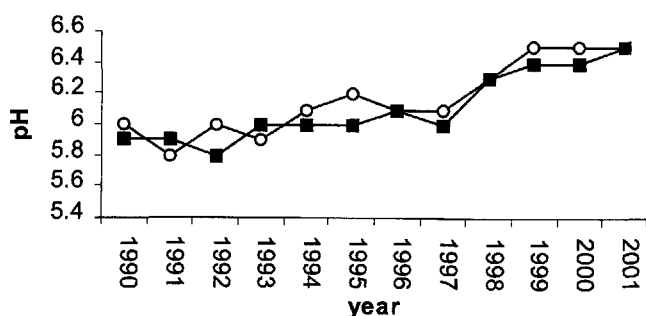


FIGURE 8. Acidity (pH) of the large (squares) and small (circles) ponds from 1990-2001.

(Cortwright 1988; Stangel 1988). Female spotted and Jefferson salamanders are known to lay a mean of approximately 200 eggs (Bishop 1941; Uzzell 1964; Shoop 1974; Wilbur 1977; Ireland 1989). If the female salamanders in my population lay a mean of 200 eggs, then the number of female spotted salamanders breeding at the two study ponds each year ranged from 1626-4913 with a mean of 3600, and the number of female Jefferson salamanders ranged from 299-502 with a mean of 426. The actual populations can be 2-3 times larger because females in some populations do not breed every year (Husting 1965; Phillips and Sexton 1989). This means that the adult female share of these populations may be as high as 10,000-15,000 spotted salamanders and 1000-1500 Jefferson salamanders.

The number of spotted salamander eggs/egg masses was greater in the large pond and was greater from 1995-1999 than 1990-1994 and 2000-2001. Females normally deposit two to four egg masses (Bishop 1941; Shoop 1974) and populations average from 58-155 eggs per mass (Bishop 1941; Stangel 1988; Downs 1989; Talentino and Landre 1991). The range of mean eggs per egg mass observed in this study from year to year (66-101) is very similar to the range that Harris (1980) observed in a North Carolina population (65-104). The range in egg mass size within and among populations may reflect annual shifts in the proportion of females that lay their clutch in 2, 3, or 4 egg masses.

Annual variation in temperature and precipitation was not correlated with the number of eggs laid or embryos surviving in these populations. Sudden cold weather during the peak of the breeding season in 1992 resulted in fewer egg masses laid (Brodman 1995). This was the only climatic event in 12 years that affected the number of eggs laid in these populations.

The mean embryo mortality rates for spotted and for Jefferson salamanders observed in this study supports predictions based on the combination of water temperature and pH (Pough and Wilson 1977). This and the strong correlation between survival and pH during the study years suggest that the increase in spotted salamander embryo survival from 1991-2001 may be due to pH increasing from 5.8 to 6.5.

The results from 12 years of monitoring salamander populations supports the prediction from competition studies (Brodman 1996, 1999) that spotted and Jefferson salamanders are in a stable coexistence. While habitat destruction has been shown to cause salamander declines (Petranka and others 1993), long-term studies on salamanders in areas where the habitat has not been destroyed do not support the global decline hypothesis (Pechmann and others 1991; Hairston 1996; Sexton and others 1998). This suggests that frogs may have experienced greater declines than salamanders. One possible bias in meta-analysis of published studies on population trends is that researchers may have been more likely to publish long-term findings that indicate significant population declines than findings of no significant trends. More long-term studies on amphibian population trends need to be reported regardless of whether the results are significant.

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